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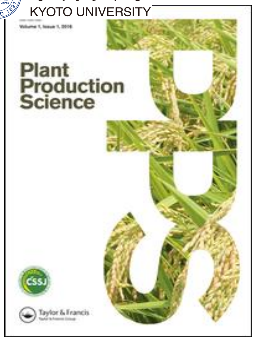

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Annual Nutrient Balance and Soil Chemical Properties in Heavy Multiple Cropping System in the Coastal Area of Southeast Lake Dianchi, Yunnan Province, China

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Abstract: To ensure higher yields, farmers in China have increased cropping intensity with a large input of chemical fertilizer and livestock manure since 1980s, which has led to unsustainable agricultural productivity and environmental quality. This study aimed to evaluate the effects of intensive cropping on nutrient absorption and biomass production of crops and to determine the controllable source of residual nutrients in soil in the coastal area of Lake Dianchi, China. Soil and crops were sampled in 32 vegetable fields and four paddy fields; and simultaneously surveyed. In vegetable fields, cropping intensity and input to each crop were extremely high; and, 58, 72, and 20% of nitrogen, phosphorus, and potassium were not absorbed by the crop. Nitrogen absorption ratios of the vegetables were low. The amount of nitrogen absorbed from sources other than chemical fertilizer by vegetables, namely, from soil, manure, or irrigation water, in the fields with three to nine years cultivation duration was higher than those with zero to two years cultivation duration. Reduction of input should be more efficient than enhancing output to decrease soil nitrogen, phosphorus, and potassium; and, reducing input of chemical fertilizer should be more efficient than reducing input of manure. These results should be helpful for reducing agricultural pollution in China.

Key words: Chemical fertilizer, China, Cropping intensity, Greenhouse vegetable, Input–output balance, Multiple cropping, Sustainable agriculture.

China has made great economic progress, which has increased the demand for agricultural products (Chen et al., 2006; Inamura et al., 2009). To obtain greater annual yields and higher profits, farmers have changed the land use type and kind of crop, and have increased cropping intensity per year. For instance, the traditional double cropping system of rice-wheat and rice-broad bean has been converted to a multiple cropping system of vegetables (Li and Wang, 2003; Min et al., 2011). Meanwhile, a large area of farmland has been lost to non-agricultural use in the progress of industrialization and urbanization (Lin and Ho, 2003). Thus, more intensive cropping and increase in breeding number of livestock are indispensable in China, particularly in the suburban area near big cities where the cultivated area declines more severely although the demands of fresh vegetable and milk severely increase with the fast economic development (Lin and Ho, 2003). It is supposed that the increasing excreta of livestock might have impact on environmental pollution directly in intensive agriculture because the excreta is used in the farmer's own cropland or sold to the neighboring farmers to be applied as manure in their cropland.

In China, there are three highly eutrophic freshwater lakes, Lake Dianchi, Taihu, and Chaohu, where the above intensive agriculture is performed in the coastal area (Liu and Qiu, 2007). In such intensive agriculture, the amount of input (chemical fertilizer and livestock manure) per year increases to maintain productivity, which is unsustainable. Soil physicochemical and biological properties may dramatically change after several years of continuous high annual inputs, and one prominent characteristic of intensive agriculture is nutrient accumulation in soil (Du et al., 2011; Lv et al., 2011; Phupaibul et al., 2004; Fang et al., 2006). In addition, the surplus nutrients in soil continuously leach into the ground and surface water throughout the year, leading to

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Abbreviations: N, nitrogen; P, phosphorus; K, potassium; NPS pollution, nonpoint source pollution; NO_3^-, nitrate; EC, electrical conductivity; TN, total nitrogen; TC, total carbon; ANCOVA, analysis of covariance.

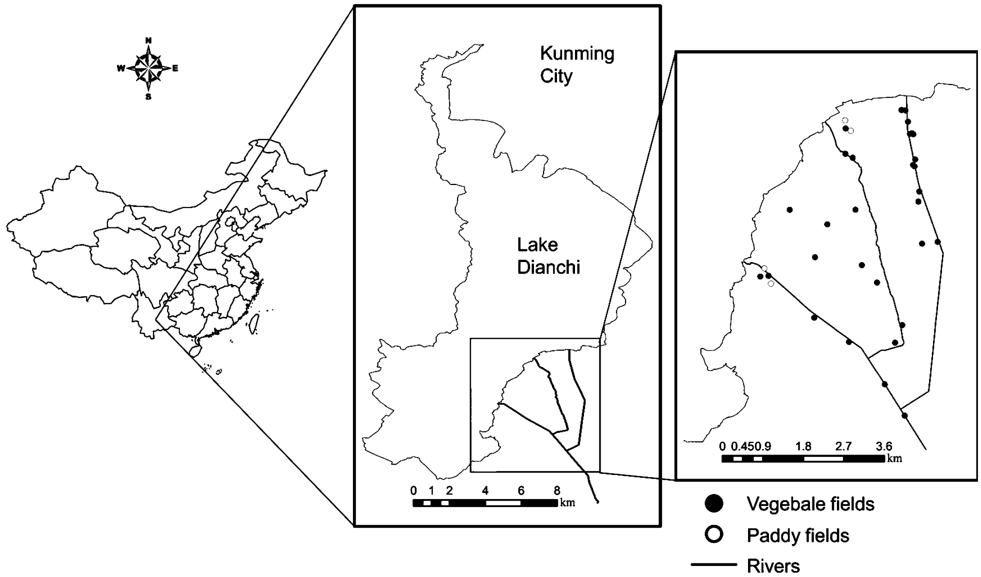

Fig. 1. Location of Lake Dianchi and study site.

nonpoint source (NPS) pollution, a principal factor of water eutrophication in China (Sun et al., 2012; Ongley et al., 2010). Current countermeasures against eutrophication of the three lakes in China can be divided into three types: (1) External nutrient loading control; for example, a pollution interception project has been performed in the region of Lake Dianchi and Lake Taihu; (2)Internal source control; countermeasures focusing on reducing the released nutrients from sediment, for example, a sediment dredging project has been used widely in eutrophic lakes in China; and (3) ecosystem recovery technology; for example, a constructed wetland was operated for agricultural runoff treatment in the Dianchi valley (Liu and Qiu, 2007; Lu et al., 2009). These countermeasures are not against the main source of pollution, abusive use of fertilizer in agriculture.

Fundamental information for sustainable agriculture which can reduce environmental pollution without profit loss of a farmhouse is required in such intensive agriculture. Many studies focused on fertilization and quality of soil, water, and sediment have been reported (Lv et al., 2011; Mao et al., 2011; Shi et al., 2011; Yang et al., 2010). For the key source of agricultural pollution, many studies have used models to estimate the actual circumstances of NPS pollution (Wu et al., 2012; Li et al., 2012; Shi et al., 2005). However, few studies have focused on the effect of intensive cultivation on soil nutrients based on annual input and output. Moreover, whether chemical fertilizer or livestock manure is the principal source of residual nutrients in soil has not been determined.

The present study was performed in multiply cropped vegetable fields in vinyl houses in the coastal area of southeast Lake Dianchi, China, and aimed to (1) determine the response of crops to high annual application of N, P, and K; (2) evaluate the influence of an intensive cropping system on nitrogen (N), phosphorus (P), and potassium (K) annual balance and soil properties; and (3) extract the principle factor resulting residual N, P, and K in soil and propose efficient methods in reducing soil nutrients. The results obtained in the coastal area of southeast Lake Dianchi, a highly eutrophic freshwater lake, are expected to be useful for the other intensive agricultural areas in China.

Materials and Methods

1. Site of study

Field experiments were conducted from March 2011 to February 2012 in the coastal area of southeast Lake Dianchi, located southwest of Kunming City, the provincial capital of Yunnan province, in southwest China (24°42′N, 102°42′E) (Fig. 1). This study area is a suburban area near the Kunming city where the residential population is 6280,000 (Statistical Bureau of Yunnan Province and Survey Office of the National Bureau of Statistics in Yunnan., 2010). It is a supply base for vegetables, flowers, meat and milk and includes three townships, Jincheng, Shangsuan, and Xinjie. Before 2000, a paddy rice-broad bean cropping system was dominant in this area, but from 2001 to 2009, the area of paddy fields decreased from 727 to 0 ha in Jincheng town, and from 700 to 0 ha in Shangsuan town. From 2006 to 2009, it decreased from 1109 to 775 ha in Xinjie town. Most of the paddy fields were changed to multiple cropping of vegetables and continuous cropping of flowers in vinyl greenhouse. Moreover, the breeding number of livestock increased sharply, for instance, from 2001 to 2009, the number of cow increased from 362 to 770 in Jincheng town and from 525 to 1191 in Shangsuan towny. The cropping system in our research area was multiple cropping of several kinds of leaf vegetables. Since the kind of leaf vegetables cultivated changes depending on the price of the crops, the cropping system changes with the farmer and year. The amount of fertilizer and manure is increased to promote early growth of vegetables and high commodity value (vegetable with deep green leaf). In various cropping systems, the annual amount of input is very high with high cropping intensity and high amount of input of fertilizer and manure per crop. Although this annually high input of chemical fertilizer and livestock manure is a cause of eutrophication, it is not clear which input is a more important factor for controlling eutrophication.

The climate in our research area is of the monsoon type. The annual precipitation is 980 mm, the rainy season extends from May to October, and 79% of annual precipitation occurs during this period. The annual transpiration is larger than the annual precipitation, and is 1876 mm. The annual mean temperature is 15ºC (National Astronomical Observatory of Japan, 2013). Soils in this area have a clayey texture and a dull brown or dull reddish brown color, the coefficients of variation of sand, silt, and clay properties not being high. The soils are classified as Eutric Cambisol (WRB soil classification) or Dystric Eutrochrept (USDA Soil Taxonomy) (Moritsuka et al., 2013).

There are three rivers with a complicated situation in the area. There are many water-gates along these rivers in this area. In the rainy season, precipitation and upstream reservoir are the main water source of the three rivers, and in the dry season, the local government pump water from Lake Dianchi to these rivers to replenish water deficiency (Tanaka et al., 2013).

2. Weather data collecting

A weather station (Weather Hawk Station, Campbell Scientific, USA) was installed in Xiaozhai village (24º41′29.90″N, 102º43′51.07″E). Reading for hourly air temperature, solar radiation, and precipitation were obtained from the station.

3. Crop management survey

On the basis of uniform distribution of sampling sites and different cultivation characteristics, 36 fields were selected (Fig. 1), and farmers were interviewed on April 30, May 1 – 3, July 14 – 16, September 26 – 28, December 9 – 11, 2011 and February 20 – 22, 2012. Four fields were cultivated with paddy rice, for the farmers' own consumption. The other 32 fields were cultivated with vegetables in vinyl houses, and therefore nutrient dynamics in the crop-soil system should not be affected by rainfall. The questions focused on the variety of crops, the year in which multiple cropping was started, cultivation calendar, and the inputs (amount of chemical fertilizer and manure) in the selected fields.

4. Plant sampling and analyses

The growth of vegetables at different sites in a vinyl house might be different; for instance, the vegetables near the entrance of the vinyl house might be slightly smaller than those in the center. Thus, we chose an area with average growth status for vegetable sampling. The aboveground biomass of vegetables that were mature enough to be harvested were sampled from three subsample points in each vegetable field. The area of a subsample point was about 0.5-m^2, and the three subsample points uniformly distributed on the diagonal line of the average growth area. Then, the sampling area was measured accurately. The indica / indica F1 hybrid varieties of paddy rice used in the study site were Chugeng and Li251. The aboveground biomass of paddy rice was sampled from three subsample points in each paddy field at physiological maturity stage (September 26 – 28, 2011). The area of a subsample point was about 4-m^2. Then, the sampling area was measured accurately. Plant samples were oven-dried at 70ºC to a constant weight and ground until they were fine enough to pass through a 2-mm sieve. The plant sample was digested by the Kjeldahl method. NH_4^+ was determined using the cresol red method (cresol red dissolved in sodium hydroxide solution, and then mixed with Hepes, the final solution was used as an indicator) (Schulze et al., 1988) and flow-injection spectrophotometer (WIS-2000, HIRANUMA, Japan); P was determined using the vanadomolybdate method (Stuffins, 1967) and a spectrophotometer (U-1500, HITACHI, Japan); and K was determined using atomic absorption spectrophotometer (AA-7000, SHIMADZU, Japan). The concentration of nitrate (NO_3^-) was determined using the Cataldo method (Cataldo et al., 1975) and spectrophotometer (U-1500, HITACHI, Japan).

5. Soil sampling and analyses

Just after plant sampling, surface soil (0 – 15 cm) samples were collected at biomass sampling points from each field. These were air-dried and ground to pass through a 2-mm sieve. Drying soil might increase nitrogen mineralization, but this change was significantly linear. Thus, it is thought that NO_3^- after drying can reflect NO_3^- levels in moist soils (Birch, 1959, 1960). Electrical conductivity (EC) and pH(H_2O) were measured using a glass electrode after the soil was mixed with distilled water (1:5, w / v). The extract was used to determine NO_3^- and P by the Cataldo method (Cataldo et al., 1975) and sulfuric acid-molybdenum method (Martin and Doty, 1949) respectively, using a spectrophotometer (U-1500, HITACHI, Japan). The concentration of K was determined with an atomic absorption spectrophotometer. Total nitrogen (TN) and total carbon (TC) were determined using a mass spectrometer (Delta S, Finnigan MAT, Bremen, Germany) coupled with an elemental analyzer (EA1108, Fisons, Rodano, Milan, Italy) at the Center for

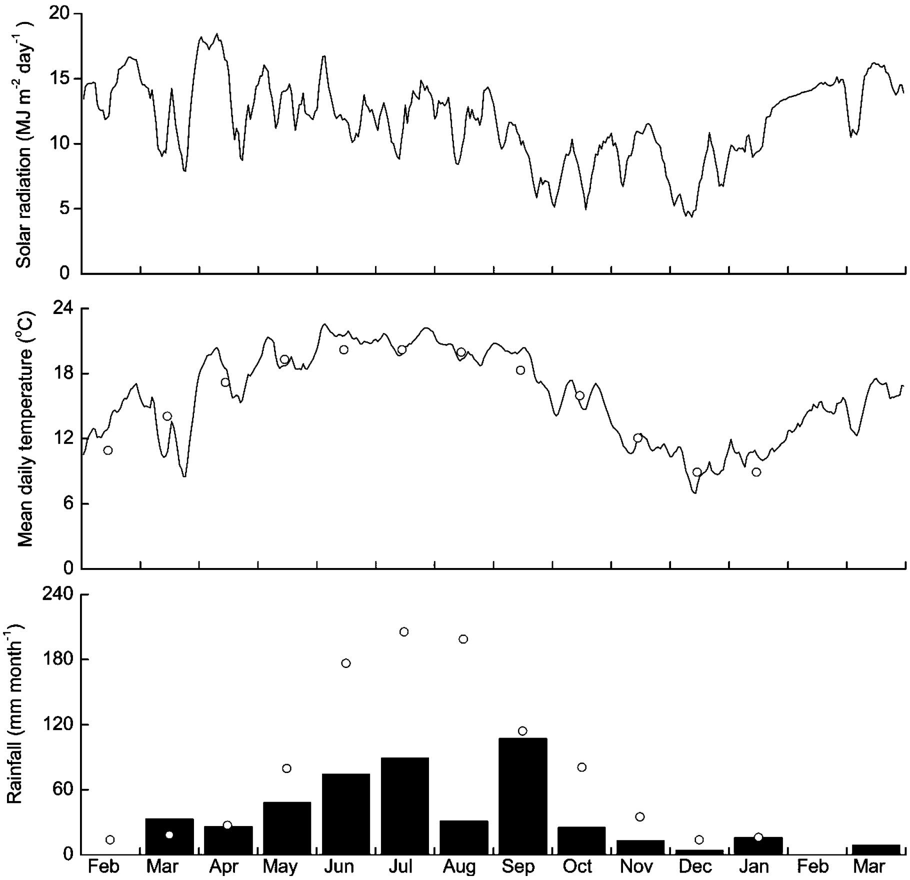

Fig. 2. Climatic conditions in the coastal area of southeast Lake Dianchi, southwest of Kunming city, Yunnan province, China. Mean daily temperature and solar radiation are 7-day moving averages, whereas rainfall data are presented as monthly totals. Data with circles represent average values in Kunming city from 1981 to 2010, cited from National Astronomical Observatory of Japan.

Ecological Research, Kyoto University (Kyoto, Japan). The annual average value was used in the analysis of data.

6. Manure data

N, P and K concentrations in manure were cited from *Fertilization Guidance for Main Crops in China* (Zhang et al., 2009).

7. Statistical analysis

Pearson correlations were calculated. Analysis of covariance (ANCOVA) was performed to identify differences among regression coefficients and regression constants.

To extract the principal components of input, output, and balance properties of N, P, and K, we performed principal component analysis with varimax rotation with eigenvalues higher than 1.0. To obtain the optimum models for predicting soil performance, we performed stepwise multiple regression analysis. Each soil component was used as a dependent variable and standardized scores of the two principal components of the 32 vegetable fields were used as independent variables. The standardized score of a principal component of a vegetable field was the total sum of products of each measured value of 32 variables on the field and with the component loading of the principal component of each of the 32 variables. Principal components and multiple regression analyses were performed with SPSS software.

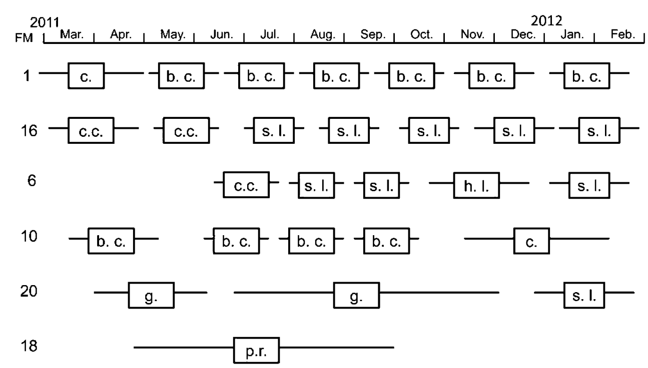

Fig. 3. Cropping sequence in representative fields in the coastal area of southeast Lake Dianchi, southwest of Kunming city, Yunnan province, China from March 2011 to February 2012, c: celery; b.c.: bok choy; c.c.: Chinese cabbage; s.l.: stem lettuce; h.l.: head lettuce; g.: garlic; p.r.: paddy rice. The line indicates the growth duration of each crop.

Results

1. Weather conditions and cultivation

Figure 2 shows the meteorological conditions from February 2011 to March 2012 at the study site. Daily solar radiation ranged from 4.4 to 18.5 MJ m^{-2}. The mean daily temperature ranged from 7 to 23.6°C, and the yearly

Table 1. Descriptive statistics of farmland area; years of multiple cropping; cropping intensity; N, P, and K input from chemical fertilizer per year; N, P, and K input from manure per year; dry matter and N, P, and K output per year; N, P, and K input–output balance; and seven properties of soil after harvesting in 32 vegetable fields and four paddy fields. Data of paddy fields are in brackets.

Variable	Unit	Mean	Maximum	Minimum	C.V.(%)
Farmland area	m^2	3185	13333	53	91
Years of vinyl house cultivation	year	4.7	9	0	54
Cropping intensity per year	crops $year^{-1}$	5.9 (1)	7 (1)	1 (1)	25 (0)
Input of chemical fertilizer per year	g m^{-2} $year^{-1}$				
N		137 (30)	297 (40)	17 (21)	45 (25)
P		31 (1.4)	97 (5.6)	7 (0)	65 (200)
K		86 (0)	187 (10.6)	10 (0)	57 (200)
Input of manure per year	g m^{-2} $year^{-1}$				
N		40 (0.8)	165 (3.3)	5 (0)	87 (200)
P		12 (0.4)	75 (1.5)	2 (0)	120 (200)
K		24 (0.4)	87 (1.7)	3 (0)	82 (200)
Output per year					
Dry matter	g m^{-2} $year^{-1}$	1692 (1216)	3272 (1609)	954 (742)	33 (38)
N		74 (9.6)	141 (11.1)	16 (8.2)	35 (18)
P		13 (2.4)	29 (3.8)	2 (1.0)	41 (67)
K		88 (10.7)	174 (12.2)	11 (8.2)	36 (18)
Input–output balance (chemical fertilizer)	g m^{-2} $year^{-1}$				
N		62 (20.4)	196 (31.6)	1 (12.7)	74 (39)
P		19 (–1)	87 (1.8)	–10 (–3.8)	113 (230)
K		–1 (–8.1)	125 (–1.6)	–122 (–12.2)	33 (57)
Input–output balance (chemical fertilizer + manure)	g m^{-2} $year^{-1}$				
N		103 (21.2)	332 (31.6)	17 (16)	62 (33)
P		31 (–0.6)	112 (1.8)	4 (–3.8)	91 (390)
K		22 (–7.6)	141 (–1.6)	–70 (12.2)	224 (61)
Soil properties after harvesting					
Total N	g kg^{-1}	3.0 (2.8)	4.1 (3.1)	1.9 (2.5)	19 (15)
Total C	g kg^{-1}	18.4 (24.3)	31.0 (25.5)	11.3 (23.1)	26 (7)
Soil NO_3^-	mg kg^{-1}	163 (44)	320 (60)	48 (28)	34 (51)
water-soluble P	mg kg^{-1}	13 (2)	50 (3)	0 (1)	107 (53)
water-soluble K	mg kg^{-1}	97 (77)	399 (94)	32 (60)	76 (32)
pH		6.9 (7.3)	7.5 (7.4)	6 (7.3)	5 (1)
EC	ms m^{-1}	81 (93)	200 (131)	22 (56)	49 (57)

Input–output balance (chemical fertilizer) = N, P, or K input from chemical fertilizer − N, P, or K output by vegetable. Input–output balance (chemical fertilizer + manure) = N, P, or K input from chemical fertilizer and manure − N, P, or K output by vegetable.

temperature change coincided with the data observed by the National Astronomical Observatory of Japan from 1981 to 2010. The rainy season extended from July 2011 to September 2011, and the dry seasons were from February 2011 to April 2011 and from October 2011 to March 2012. The rainfall from February 2011 to January 2012 was 466 mm, and it was less than the mean value from 1981 to 2010, affecting cultivation. The highest cropping intensity was eight in the past, but decreased to seven because of a lack of irrigation water.

The vegetables grown were mainly leafy and divided into two types: short-term varieties (growth duration in a field is 30 to 50 days), such as bok choy (*Brassica rapa* L. var. *chinensis*), stem lettuce (*Lactuca sativa* L.), and long-term varieties (growth duration in a field is more than 50 days), such as celery (*Apium graveolens* L. var. *dulce*) (Fig. 3). These vegetables were transplanted in many cases and this is also one of the reasons for the short growing duration in a field. Some farmers chose to cultivate short-term varieties throughout the year, whereas others cultivated one or two long-term varieties in winter and several short-term varieties at other times. During the period of 5 – 10 days after harvest, the underground parts of vegetables were returned to the deeper soil layer, and the residue was composted nearby and

Table 2. Correlation coefficients of years of multiple cropping and cropping intensity with input from chemical fertilizer and manure per year, output per year, input–output balance (chemical fertilizer + manure) per year, and seven properties of soil after harvesting in 32 vegetable fields.

	Years of multiple cropping	Cropping intensity
Years of multiple cropping	1	
Cropping intensity	0.357*	1
N input from chemical fertilizer and manure	0.489**(0.383*)	0.504**(0.404*)
P input from chemical fertilizer and manure	0.423* (0.319)	0.434* (0.335)
K input from chemical fertilizer and manure	0.544**(0.441*)	0.603**(0.521**)
Dry matter output	0.388* (0.327)	0.370* (0.304)
N output	0.472**(0.356*)	0.532**(0.441*)
P output	0.503**(0.424*)	0.384* (0.253)
K output	0.520**(0.418*)	0.523**(0.422*)
N input–out balance (chemical fertilizer + manure)	0.420* (0.320)	0.414* (0.312)
P input–out balance (chemical fertilizer + manure)	0.335 (0.234)	0.368* (0.282)
K input–out balance (chemical fertilizer + manure)	0.289 (0.186)	0.354* (0.281)
Soil total N after harvesting	−0.068 (−0.018)	−0.145 (−0.130)
Soil total C after harvesting	−0.241 (−0.118)	−0.390* (−0.335)
Soil NO_3^- after harvesting	−0.315 (−0.303)	−0.092 (0.023)
Soil water-soluble P after harvesting	0.076 (0.099)	−0.046 (−0.079)
Soil water-soluble K after harvesting	−0.027 (−0.073)	0.115 (0.133)
Soil pH after harvesting	−0.041 (−0.084)	0.104 (0.127)
Soil EC after harvesting	0.207 (0.146)	0.207 (0.146)

** and * denote significant at 0.01 and 0.05 level, respectively. Data in brackets represent the partial correlation coefficients of corresponding variable in the row and variables in the column, controlling factor is another variable in the row.

returned to the field. Most farmers performed cultivation activities year round. Chemical fertilizer used in this area is mainly compound fertilizer with different N-P-K ratios and urea, and it is applied as basal fertilizer and / or topdressing for each crop. The manure is mainly cow manure and is applied once or twice in a year as basal fertilizer.

2. Descriptive statistics of collected data

Table 1 shows the descriptive statistics of cultivation, input–output balance, and soil properties. Farmland area per farmer household ranged from 53 to 13333 m^2. There were great differences in years of multiple cropping, ranging from 0 to 9 (0 years imply that single cropping of paddy rice had just been converted to multiple cropping of vegetable). Thus, this situation was helpful for estimating the influence of multiple intensive cropping in the area. Among the 32 vegetable farmers, five farmers cultivated five crops per year, and 23 farmers cultivated six or seven crops per year. The four paddy rice farmers cultivated one crop per year.

The intensive cropping system depended on application of large amounts of chemical fertilizer and manure. Large amounts of chemical fertilizer and manure were applied in vegetable fields. In contrast, limited application of chemical fertilizer was needed for paddy rice fields, and little or no manure was used. In vegetable fields, the input–output balance (input included chemical fertilizer and manure) showed that 58.2% of N, 72.1% of P and 20% of K were not absorbed by vegetables. The C.V. values of K balance were high, and K balance in some fields was negative. In paddy fields, little N remained and input–output balances of P and K were negative.

NO_3^-, water soluble P, and water soluble K in vegetable fields were higher than those in paddy fields, and pH in vegetable fields were lower than those in paddy fields.

Since the correlation matrix of all variables in table 1 is too large to present, it is divided into two smaller tables, table 2 and table 3. Table 2 shows the effects of years of multiple cropping and cropping intensity on the other major variables. Years of multiple cropping was significantly correlated with cropping intensity, three variables of input from chemical fertilizer and manure, four variables of output, and N input–output balance (chemical fertilizer + manure). Cropping intensity was significantly correlated with three variables of input from chemical fertilizer and manure, four variables of output, three variables of input–output balance (chemical fertilizer + manure), and soil total C. Years of multiple cropping and cropping intensity did not show a significant correlation with seven properties of soil after harvesting, except total C. Table 3 shows the

Table 3. Correlation coefficients of input from chemical fertilizer and manure per year, output, input–output balance (chemical fertilizer + manure) per year with seven properties of soil after harvesting in 32 vegetable fields.

	Input from chemical fertilizer and manure			Output				Input–out balance (chemical fertilizer + manure)		
	N	P	K	dray matter	N	P	K	N	P	K
Soil total N after harvesting	0.029	0.151	0.086	0.301	0.085	0.303	0.323	0.003	0.097	−0.108
Soil total C after harvesting	−0.125	−0.026	−0.029	0.302	−0.091	0.151	0.128	−0.120	−0.054	−0.115
Soil NO_3^- after harvesting	−0.272	−0.076	−0.128	−0.105	−0.271	−0.191	−0.117	−0.230	−0.040	−0.070
Soil water-soluble P after harvesting	−0.024	0.422*	−0.083	0.050	−0.190	−0.080	−0.066	0.047	0.439*	−0.052
Soil water-soluble K after harvesting	−0.111	0.370*	0.018	−0.235	−0.254	−0.233	−0.076	−0.036	0.415*	0.069
Soil pH after harvesting	0.234	−0.083	−0.001	0.310	0.357*	0.328	0.225	0.148	−0.144	−0.146
Soil EC after harvesting	0.147	0.088	0.303	0.357*	0.155	0.179	0.268	0.121	0.057	0.175

* denote significant at 0.05 level.

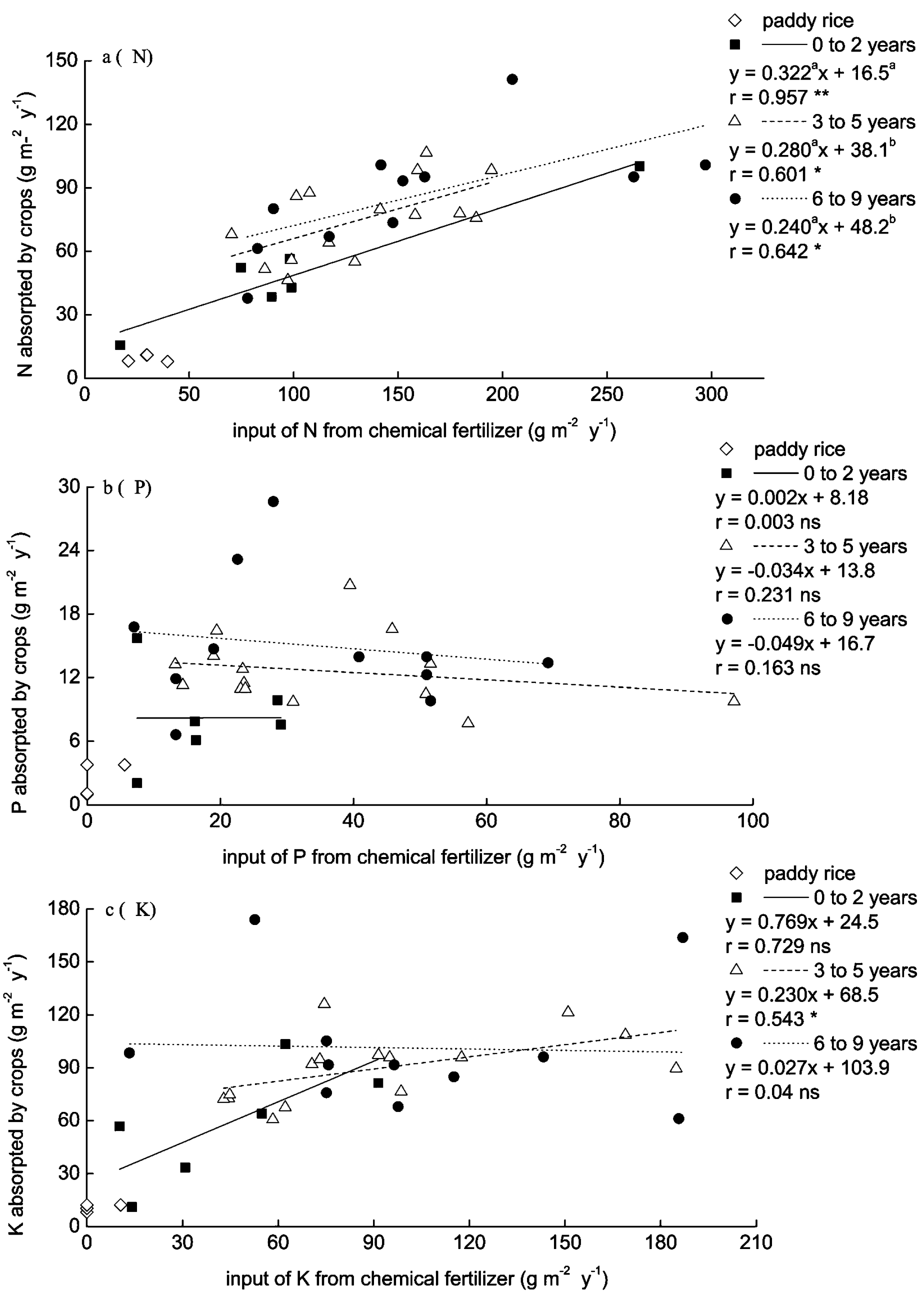

Fig. 4. Relationship between input amounts of N, P, and K from chemical fertilizer and N, P, and K absorption by crops in paddy fields and vegetable fields under multiple cropping (0 – 2, 3 – 5, and 6 – 9 years) from March 2011 to February 2012. **, * and n.s denote significant at $P < 0.01$, significant at $P < 0.05$ and not significant, respectively. Different letters on the right shoulder of regression coefficients and regression constants indicate significant differences ($P < 0.05$).

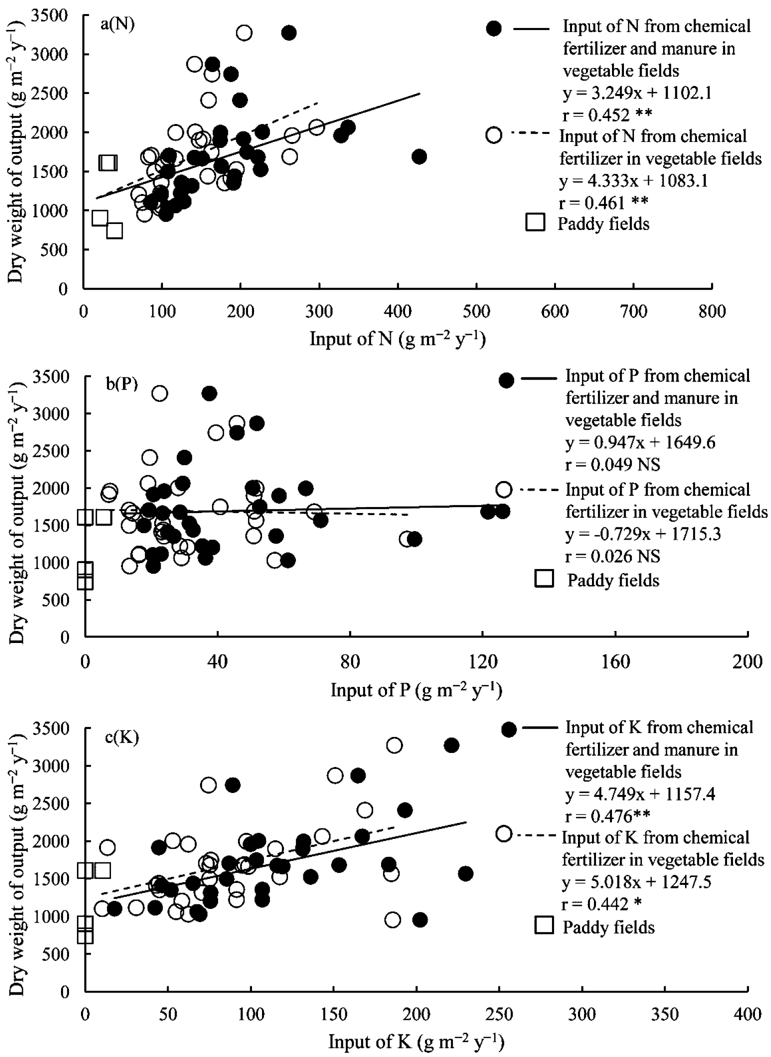

Fig. 5. Relationship between input of N,P, and K and dry weight of output in the vegetable fields. **, * and n.s denote significant at $P < 0.01$, significant at $P < 0.05$ and not significant, respectively.

effects of input from chemical fertilizer and manure per year, output, and input–output balance (chemical fertilizer + manure) per year on seven properties of soil after harvesting. P input from chemical fertilizer and manure per year and P input–output balance (chemical fertilizer + manure) per year were significantly correlated with soil water-soluble P after harvesting.

3. Crop absorptive response to input of N, P, and K

Vegetable fields were divided into three types depending on different cultivation duration under multiple cropping (0 – 2, 3 – 5, and 6 – 9 years). Significant correlations were observed between input N from chemical fertilizer and N absorbed by vegetable in the three types of fields (Fig. 4a). According to the result of ANCOVA, there were no significant differences among the three regression coefficients. The regression constant for 0 – 2 years under multiple cropping was significantly lower than the others.

Figure 4b and 4c indicated that the correlations between input of P, K from chemical fertilizer and P, K absorbed by the vegetable were not significant, except for K in 3 – 5 years under multiple cropping.

Compared with vegetable fields, the N, P, and K of input and absorption in paddy fields were low.

4. Crop biomass response to input of N, P, and K

The dry weight of output of N significantly correlated with both input of N from fertilizer (including chemical fertilizer and manure) and input of N from chemical fertilizer (Fig. 5a). Neither input of P from fertilizer (including chemical fertilizer and manure) nor input of P from chemical fertilizer significantly correlated with the dry weight of output of P (Fig. 5b). The dry weight of output of K significantly correlated with both input of K from fertilizer (including chemical fertilizer and manure) and input of K from chemical fertilizer (Fig. 5c).

Compared to vegetable fields, little or no input of N, P, and K supported a certain amount of dry weight of output in paddy fields (Fig 5 a, b, and c).

5. Principal component analysis

The results of Pearson correlation analysis showed

Table 4. Component loading, eigenvalue and percentage of total variance explained for the first two principal components of N.

Variable	PC1	PC2
Nitrogen input property		
Chemical fertilizer	***0.897***	0.31
Manure	0.55	0.13
Nitrogen output property		
Nitrogen output	0.452	***0.848***
Dry matter output	0.277	***0.804***
Absorption rate	−0.291	***0.812***
Nitrogen input–output balance property		
Chemical fertilizer	***0.92***	−0.046
Chemical fertilizer + manure	***0.971***	0.04
Eigenvalue	3.261	2.143
Ratio of cumulative contribution	0.466	0.772

Table 5. Component loading, eigenvalue and percentage of total variance explained for the first two principal components of P.

Variable	PC1	PC2
Phosphorus input property		
Chemical fertilizer	***0.938***	−0.074
Manure	0.577	0.418
Phosphorus output property		
Nitrogen output	−0.092	***0.938***
Dry matter output	−0.050	***0.894***
Absorption rate		
Phosphorus input–output balance property		
Chemical fertilizer	***0.914***	−0.283
Chemical fertilizer + manure	***0.989***	0.005
Eigenvalue	3.036	1.940
Ratio of cumulative contribution	0.506	0.829

significant correlations among input property, output property, and input–output balance properties. For example, input of N from chemical fertilizer was significantly correlated with N output (Fig. 4a). Significantly correlated variables cannot be used as independent variables in a multiple regression analysis. For this reason, principal component analysis was used to integrate the input, output, and input–output balance properties independently (Table 4, Table 5, and Table 6). By varimax rotation, principal component analysis extracted 2 components (PC1 and PC2) with eigenvalues greater than 1.0 for each of N, P, and K, and these accounted for 77.2, 82.9, and 81.8% of the total variance, respectively. The first component (PC1) showed high loading with input from chemical fertilizer, input–output balance (chemical fertilizer), and input–output balance (chemical fertilizer + manure). The component loadings of N, P, and K input from manure were lower than those from chemical fertilizer, and after adding the component loadings of N, P, and K input–output balances from manure, the component loadings of N, P, and K input–output balances from chemical fertilizer and manure did not become as high as those from chemical fertilizer. The second component (PC2) showed high loading with the output property of N, P, and K.

Table 6. Component loading, eigenvalue and percentage of total variance explained for the first two principal components of K.

Variable	PC1	PC2
Potassium input property		
Chemical fertilizer	***0.885***	0.398
Manure	0.135	0.558
Potassium output property		
Nitrogen output	−0.127	***0.945***
Dry matter output	0.082	***0.883***
Absorption rate		
Potassium input–output balance property		
Chemical fertilizer	***0.978***	−0.168
Chemical fertilizer + manure	***0.978***	0.057
Eigenvalue	2.735	2.173
Ratio of cumulative contribution	0.456	0.818

Table 7. Contribution of each principal component to N, P and K in soil and R^2 and *P*-value of models.

Soil component	PC1	PC2	R^2	*P*
N	0.691	0.309	0.272	0.013
P	1.000	–	0.159	0.027
K	0.808	0.192	0.198	0.063

6. Multiple regression analysis for predicting soil components

The following equations showed the most appropriate models for the performance of each soil component.

$N_{soil} = 149.48 + 0.858 \times PC1 - 0.383 \times PC2$

$P_{soil} = 12.79 + 0.074 \times PC1$

$K_{soil} = 107.19 + 0.136 \times PC1 - 0.032 \times PC2$

In Table 7, the magnitude of each standardized score of principal component in its contribution to the performance of soil components was determined by the regression coefficients in the above equations. R^2 indicates the proportion of the variation explained by each model with respect to the total variation in soil components.

PC1 and PC2 explained 27.2% of the total variance for soil N, and 19.8% for soil K, PC1 contributed to soil N and K in larger magnitude than PC2, and PC2 showed negative contributions to soil N and K. For soil P, the contribution of PC2 to soil P was not significant, and PC1explained 15.9% of the total variance.

Discussion

1. Comparison of intensive management and its influence on soil

For other multiple cropping systems in China, Shi et al. (2009) found that vegetable producers in south-Eastern China usually grew three crops per year in the same field. In the Yangtze River delta region, two or three crops per year were recorded in greenhouse fields (Huang et al., 2006). The northern plain is the main vegetable-producing area in China and two or three crops were grown in this area (Ju et al., 2007). In our research area, however, most farmers cultivated six or seven crops per year. This very high cropping intensity is based on the combination of vegetables with a short growing duration and transplanting culture. Kunming city is famous in China as “Spring City” with solar radiation and temperature suitable for vegetable cultivation year round (Fig. 3), and this area is adjacent to Lake Dianchi providing abundant water. Moreover, the multiple cropping was carried out within the vinyl greenhouse which promotes growth of vegetables. In our research area with high annual transpiration, the vinyl greenhouse aims at keeping humidity in addition to keeping warm. The greatest reason for high intensity is for fulfilling the huge demand, for instance, the winter demand in southern China, where vegetable cultivation is limited by low temperatures.

In south-eastern China, total inputs of N, P, and K were 126, 46, and 52 g m^{-2} y^{-1} and the inputs of N, P, and K to each crop were 42, 15, and 17 g m^{-2}, respectively (Shi et al., 2009). In the Yangtze River delta region, total inputs of N, P, and K were 142, 44, and 60 g m^{-2} y^{-1}, and the inputs of N, P, and K to each crop were 55, 20, and 25 g m^{-2}, respectively (Huang et al., 2006). In northern China, total inputs of N, P, and K were 282, 93, and 93 g m^{-2} y^{-1} and inputs of N, P, and K to each crop were 110, 37, and 37 g m^{-2}, respectively (Ju et al., 2007). By contrast, total inputs of N, P, and K were 177, 44, and 110 g m^{-2} y^{-1} in our research area, and inputs of N, P, and K to each crop were 30, 7, and 18 g m^{-2}, respectively (Table 1). In comparing with these areas, the high total input per year in our research area appeared to depend on high cropping intensity, which is the reason why cropping intensity was significantly correlated with N, P, and K input from chemical fertilizer and manure (Table 2). Considering neighboring countries, in Hanoi city, Vietnam, six to nine crops were recorded in intensively cultivated vegetable fields. Total inputs of N, P, and K were 92, 23, and 54 g m^{-2} y^{-1}, respectively, on average, and inputs of N, P, and K to each crop were 10 – 15, 0.4 – 4, and 2 – 9 g m^{-2}, respectively (Khai et al., 2007). In Suphan Buri-Nakhon Pathom provinces, Thailand, intensities in some vegetable fields ranged from five to seven, and total inputs of N and P to each crop were 6 and 0.2 g m^{-2}, respectively (Phupaibul et al., 2002). Compared with these areas, the high total input per year in our research area depended on high inputs to each crop.

In our research area, NO_3^-, water-soluble P and K in vegetable fields were higher than those in paddy fields. Similar accumulation of nutrients in soil occurred in China. In south-eastern China, soil TN, extractable NO_3^-, available P, and exchangeable K concentrations increased from 1.63 to 2.01, 0.1 to 0.25, 0.16 to 0.3, and 0.22 to 0.25 g kg^{-1}, respectively, in a two years plot experiment (Shi et al., 2009). In the Yangtze River delta, TN, extractable NO_3^-, available P, and exchangeable K concentrations in vegetable fields were 1.6, 0.19, 0.14, and 0.15 g kg^{-1}, but those in barren were 1.0, 0.11, 0.05, and 0.08 g kg^{-1}, respectively (Huang et al., 2006). In northern China ,TN, extractable NO_3^-, available P, and exchangeable K concentrations in the vegetable fields under multiple cropping were significantly higher than those in the wheat-maize rotation fields (Ju et al., 2007).

Table 2 shows that soil total C tended to decrease with increasing intensity of cropping. In our research area, local farmers do not apply extraneous C sources to vegetable fields. Meanwhile, the mainly applied livestock manure is cow manure, and the main feeding to cow is locally unused leaves of vegetables. The input of C is limited, and the output of C increases with increasing intensity of cropping. Moreover, the decomposition of organic matter is enhanced under more aerobic and warmer conditions in vinyl houses. These should be the reason why total C tended to decrease with increasing intensity of cropping (Moritsuka et al., 2013).

Guo et al. (2010) reported that intensive cropping management with large input of chemical fertilizer induced decline of 0.3 – 0.8 in soil pH in high-input fields, such as vegetables, fruits, and tea fields, and decreased soil pH below 6.0 in major Chinese croplands, inhibiting growth of crop roots and affecting nutritional absorption. In our study area, the mean pH value of the four paddy fields was 7.3, the mean pH value of vegetable fields was 6.9, and the lowest value was 6, which was comparatively high and might be due to the conventional application of alkaline materials for controlling clubroot disease.

2. Crop response to intensive cropping

Figure 4a shows significant correlations between input of N from chemical fertilizer and N absorbed by vegetables in 0 – 2, 3 – 5, and 6 – 9 years under multiple cropping. The regression coefficient reflects the N absorption ratio, and the absence of significant differences among the three regression coefficients indicates that N absorption ratios in the three types of fields were not significantly different. The N absorption ratios of vegetables in the greenhouse in Japan ranged from 0.31 to 0.46 (Nishio et al., 2001); those in our research area were lower, ranging from 0.24 to 0.32

(Fig. 4a). Improvement of N absorption ratio can reduce the demand of N fertilizer and residual N in soil. Previous studies proved that application of slow-release fertilizer and utilization of split application could raise the N absorption ratio (Shaviv and Mikkelsen, 1993; Sowers et al. 1994). The regression constant reflects N absorption from sources other than chemical fertilizer, namely, from soil, manure, or irrigation water. The regression constant of 3 – 9 years under multiple cropping was significantly higher than 0 – 2 years, indicating that vegetables absorbed massive N from sources other than chemical fertilizer in 3- to 9-year fields.

The correlations between input P from chemical fertilizer and P absorbed by vegetable were not significant (Fig. 4b). This result may be due to the abundant P in soil or manure, which affects the response of vegetables to inputs of P from chemical fertilizer.

The correlations between dry weight of output and input of N from manure, and between dry weight of output and input of K from manure were not significant (data not shown). The significant correlation between dry weight of output and input of N from chemical fertilizer and manure should be due to the significantly positive response of dry weight of output to the input of N from chemical fertilizer (Fig.5a), and the output and input of K should be the same as those of N (Fig. 5c). The amount of applied nutrient exceeds the amount needed by the crop in many intensive cropping fields (Zhu et al., 2005). Input in some fields in our research area might be excessive, according to the local government's advice card, whose recommended standard application of N from chemical fertilizer to spinach and celery were 13.1 g m^{-2} and 27.9 g m^{-2} per crop, respectively. The actual mean input of N from chemical fertilizer to spinach and celery were 28.8 g m^{-2} and 75.6 g m^{-2} per crop. The data of input of N that greatly exceed 200 g m^{-2} y^{-1} are comparatively few (Fig. 5a), thus the response of dry weight of output to input of N that exceeds this level is uncertain. Since more data for input over 200 g m^{-2} y^{-1} is needed for more discussion, in this paper, we do not discuss the data for over 200 g m^{-2} y^{-1}. Figure 5b indicates that vegetable yields could not be improved by increasing the input of P.

3. Efficient method for reducing soil N, P, and K

Elucidation of the relations among annual input, annual output, annual input–output balance, and chemical properties of soil in such various cropping systems is important to obtain the underlying data for improvement of cultivation. However, there are few reports on these systems. We used statistical methods to elucidate the relations useful for mitigation of eutrophication.

The first component (PC1) showed higher loading of N, P, and K inputs from chemical fertilizer than from manure, implying that higher inputs from chemical fertilizer simultaneously increased the value of input–output balance (chemical fertilizer) and input–output balance (chemical fertilizer + manure), and that inputs of N, P, and K from chemical fertilizer increased N, P, and K concentrations in soil to a larger extent than did inputs of N, P, and K from manure (Tables 4, 5, and 6). It was thought that the relative lowness of the effect of manure resulted from the low amount of application as compared with chemical fertilizer. If the ammonia vaporization of the manure in a field is taken into consideration, the actual contribution of manure may be still lower. The second component (PC2) showed high loading with output properties other than absorption ratios for P and K, and with the absorption ratio for N. A large dry matter output corresponded to a large N output. It also corresponded to large aboveground part, indicating crops had abundant underground organization, which could enhance the absorption ratio.

Except PC1 and PC2, other elements might contribute to soil N, P, and K, such as leaching nutrients and nitrogen loss by gaseous forms through denitrification, which was the reason why the components only explained 27.2, 15.9, and 19.8% of the total variance of soil N, P, and K, respectively. In terms of the elements used in multiple regression analysis, PC1 contributed to the N and K concentrations in soil with a larger magnitude than PC2 (Table 7), and the contribution of PC2 to soil P was not significant, indicating that it would be more efficient to reduce the N, P, and K in soil by reducing input than by enhancing output. As mentioned above, N, P, and K from chemical fertilizer played a more important role than those elements from manure, but the local government has sometimes taken the policy which controls the contamination from manure by building an area which restricts breeding of livestock and poultry (Li et al., 2011). This effect is considered to be low in view of our results, except inhibition of direct inflow of manure to river. Probably, control of the application of chemical fertilizer should also be promoted simultaneously. PC2 showed a negative contribution to N and K in soil, suggesting that increasing N and K output would reduce soil N and K. However, it is contradictory to reduce the amount of input and to increase the amount of output. An effective and available management method would be to increase the vegetable productivity by increasing inputs of K from chemical fertilizer under sufficient input of N. Feike et al. (2010) reported that intercropping used environmental resources more efficiently and generated high and stable output. This cropping method has seldom popularized in our study area, because the transplantation and harvest work are complicated, but it would be worthwhile to be introduced. In large areas, cruciferous vegetables were observed to suffer from clubroot disease, probably caused by fungi. N output would be improved by controlling the disease with application of alkaline materials and fungicide, while, application of alkaline materials would also increase soil pH, improving the output. Although the local government has established a standard for using chemical fertilizer, extension work is lacking, leaving most farmers to depend on personal experience to apply fertilizer. In addition, only one standard was established for the whole area, it is essential to formulate several more detailed standards which consider different soil fertilities of different sites.

As mentioned above, the cultivation in farmers' fields consisted of several kinds of leaf vegetables. Thus it is difficult to analyze the relations among annual input, annual output, annual input–output balance, and the chemical properties of soil for each kind of vegetable. The above-mentioned relations which covered several kinds of leaf vegetables should be clarified by a field experiment, and then the relations according to each kind of vegetable should be clarified by the pot experiment using soil of the farmer's field. Demonstration of the principle of decreasing N, P, and K in soil by controlling input N, P, and K from chemical fertilizer maintaining productivity requires further pot or local field experiments.

Conclusions

The present survey revealed that cropping intensity in most vegetable fields and input of N, P, and K to each crop was extremely high. By the synergistic effect of the two factors, the annual amount of input was extremely high. Input–output balance results showed that 58.2, 72.1, and 20% of N, P, and K, respectively, were not absorbed by the vegetable under over-fertilization. ANCOVA results suggested that the N absorption ratio in the vegetable field could be raised further, and that the amount of mineralized N absorbed from a source other than chemical fertilizers by the vegetable under multiple cropping with longer cultivation duration was increasing. The fertilization method needs to be improved based on these results, for instance, slow-release fertilizer and split application might increase N absorption ratio. Regression analysis of P and K suggested that vegetables absorbed P and K independent of the input of P and K from chemical fertilizer. Dry weight of output significantly correlated with N and K input, but the response of dry weight of output to input of N that greatly exceeds 200 g m^{-2} y^{-1} is uncertain. The increasing input of P could not improve the dry weight of output. Principal component analysis revealed that concentrations of N, P, and K in soil increased to a larger extent with input of N, P, and K from chemical fertilizers than from manure. Multiple regression analysis indicated that reducing the input of N, P, and K would be more efficient than increasing their output. From the above point of view, the following approach was considered to be effective and practical for the farmer. First, dry weight of output is ensured by control of soil disease damage and by the improvement of fertilizing balance. Second, the amount of applied chemical fertilizer is controlled in a range that does not decrease the agricultural income. Finally, the amount of residual nutrients in soil is controlled by the reduction of the applied chemical fertilizer and by the effective use of soil mineralization N.

In China, intensive agriculture is assumed to expand with further economic development. These results and analysis approaches should be helpful for reducing agricultural pollution in China.

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